



RELATION BETWEEN PHOTOGRAPHIC NEGATIVES AND THEIR POSITIVES.

BY F. HURTER, PH.D., AND V. C. DRIFFIELD.

THE photo-chemical investigations which we had the honour to bring before this Section were undertaken with a view to render photographic operations more certain and reliable than they are at present, and by this communication we wish to direct the attention of photographers to the advantages of scientific procedure over rule of thumb manipulation. We propose to produce, by contact printing, a negative from a transparent positive, and from a negative two positives; the three being produced upon three entirely different plates. We hope to prove that we can produce the best possible result upon these plates with certainty, without making any calculations, and that, although a knowledge of logarithms is necessary for the appreciation of our theory, no such knowledge is required to carry out our practice, which indeed is simplicity itself.

In order to be successful in photographic operations it is essential to know exactly the properties of the plates we intend to use. We must know their sensitiveness to light, their behaviour during development, and their behaviour to negatives, if transparencies and secondary negatives are to be produced.

We think it well shortly to recapitulate as much as is necessary of what we have already published, so that the principles on which our operations depend may be properly understood.

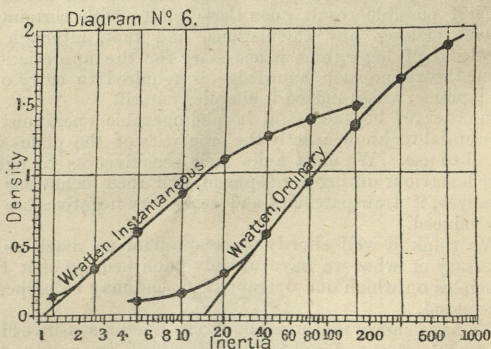
We have shown that when light acts upon a sensitive film, the growth of the density of the resulting image (*i.e.*, the amount of reduced silver) is at first proportional to the intensity of the light, but that, owing to the decreasing amount of unaltered silver salt, the density grows less rapidly with prolonged exposure; a period now supervenes when it ceases to grow at all, and at last it decreases if the exposure be unduly prolonged. We have shown that for every plate there exists a range of exposures during which

the growth of the density is proportional to the logarithm of the exposure, and this range we termed the "period of correct representation."

Now, what we aim at, in studying our plates, is to ascertain this range of exposures. The method of doing so is simple. We expose different portions of a plate to the light of a standard candle placed at a distance of one metre from the plate for various periods of time, every successive exposure being double the previous one. After development we measure the amount of silver reduced by our photometric method.

The densities thus obtained, when plotted on a diagram, furnish the "characteristic curve" of the plate. We refer you to diagram No. 6, which shows the characteristic curves of the Wratten "ordinary" and "instantaneous" plates, which we intend to use to-night.

RELATION BETWEEN PHOTO-NEGATIVES AND THEIR POSITIVES.



The lower horizontal scale is a scale of exposures, the vertical scale the scale of densities. The divisions of the exposure scale are similar to those of an ordinary slide rule. The divisions of the vertical scale are all equal, and the distance between 0. and 1.00 on this scale is exactly equal to the distance between 1 and 10 on the exposure scale.

In order to save trouble we have had skeleton diagrams with these scales lithographed, and members are welcome to copies. They are exceedingly convenient for plotting characteristic curves and making other memoranda of experiments.

It will be seen that the two curves on this diagram are very similar, but they are situated on different portions of the exposure scale. The one plate requires much shorter exposures for the production of the same density than the other. The more to the left of the exposure scale the curve is situated, the faster is the plate.

The curve itself consists of three distinct portions. The lower strongly curved portion is the period of under-exposure; the middle portion, almost a straight line, is the period of correct representation; the upper curved end is the period of over-exposure.

The middle or straight line portion of this curve embraces the only useful range of exposures, and the only one which interests us to-night. If we produce this straight line until it intersects the scale of exposures, the point of intersection marks a particular exposure, viz., the shortest, which will produce a density very nearly at the beginning of the period of correct representation. We have shown that this point of intersection is practically independent of the length of time of development.

Diagram No. 7 shows the divisions of the characteristic curve into three periods more clearly. The curves on this

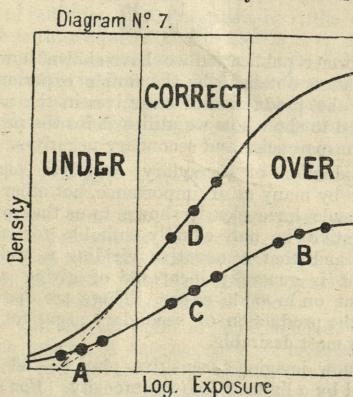


diagram are two of the infinite number which are all characteristic of the same plate, and which result from differences in the length of time of development. The shorter the time of development the less inclined is the straight line, and as development is prolonged, the more inclined does the straight line become, but, whatever the inclination, it would still intersect the exposure scale at the same point.

It is important to know what length of time development must last in order to reach any particular inclination of this straight line. We therefore develop the plate, when determining its speed, for an exact time at a specified temperature, and note the inclination of the line by drawing through the point 1,000 on the exposure scale, a line parallel to the straight part of the characteristic, noting its point of intersection with the density scale. This gives us the value of the tangent of the angle of inclination, which value we term the "development constant." Knowing the value of this constant for one time of development, we can approximately determine the time it would take to reach any other constant, but our results in this respect are not yet sufficiently complete for publication.

We may here say that, in our first paper (9, 467), we gave a formula for the calculation of the development factor γ , which, we regret to say, was accidentally inverted.

It should stand—

$$\gamma = \frac{D_2 - D_1}{\log. E_2 - \log. E_1}.$$

In our former publication we have shown how we utilise the information obtained by the simple experiment with a candle for the production of negatives in the camera; we now proceed to show how we utilise it for the production of positive transparencies and secondary negatives.

The production of secondary negatives may not be considered by many as of importance, but other researches we have made have clearly shown to us that one and the same negative is not equally suitable for all printing processes, and that a negative yielding a good ordinary silver print is generally incapable of giving a first-class enlargement on bromide paper. There are therefore cases in which the production of secondary negatives of special qualities is most desirable.

Let us now imagine a sensitive plate behind a negative illuminated by a light of known intensity. For simplicity's

sake let the negative have only one or two different opacities. Let the opacities of the negative be 40, 20, and 10, then we should expect the plate to be illuminated behind the negative with $\frac{1}{40}$, $\frac{1}{20}$, and $\frac{1}{10}$ the original intensity of the light. Experiment reveals, however, that this is not so, but that the results of exposures to the light behind the negatives are greater than those which would be produced by $\frac{1}{40}$, $\frac{1}{20}$, and $\frac{1}{10}$ of the original light intensity. The reason for this is not far to seek. When the light shines on the plate directly, say about 70 to 80 per cent. of the light is reflected by the plate into space. When a negative is placed in front of the plate the light is similarly reflected by the sensitive surface, but a considerable portion of it is at once reflected back again by the two reflecting surfaces of the negative, so that behind a negative less of the light transmitted by it is lost by reflection from the sensitive film, and consequently more work is done on the film than would be the case if the same intensity of the light were to act upon a film free to reflect.

Suppose the naked film were exposed to light of unit intensity. It would reflect into space the fraction R of light. Of the rest $(1 - R)$, some would be absorbed and some would pass through the plate. If, however, a negative be placed in front of the sensitive film, then the fraction R of the light cannot be reflected wholly into space; a portion of it is reflected back again upon the film, and if the coefficient of reflection of the negative be r , the amount of light which is thus returned to the film is Rr . Secondary, tertiary, &c. reflections add small amounts R^2r^2 , R^3r^3 , &c. to this. The result is that the effect of unit light coming through a negative is greater than the effect of unit light when the film can reflect freely, and is represented by the amount—

$$1 + Rr + R^2r^2 + R^3r^3 + \dots = \frac{1}{1 - Rr}$$

or, what is the same thing, the opacity of the negative appears to be reduced by a fraction $(1 - Rr)$. It will therefore be seen that the same negative will give different results upon different printing surfaces, according to the amount of light which these surfaces reflect.

There is still another point to be considered. When we measure the opacity of the negative, we measure it chiefly to the yellow rays of the lamp, whilst those rays are least active upon the plate. The opacity of the negative to the

blue rays is in all cases we have tested greater than the opacity to the yellow rays.

These considerations will explain why, when a negative is used for contact printing, its opacity must be considered as less than that indicated by our instrument; and when it is used for enlargement the opacity must be considered as greater than that measured in our instrument, because, in the one case, the sensitive surface cannot reflect freely, whilst in the other it does so.

The exact amount, therefore, by which we have to increase or decrease the value of the opacity of the negative depends upon the reflection of the film, upon its sensitiveness to different portions of the spectrum, and upon the colour of the negative.

If it were not for these corrections the relation between a negative and its positive could be at once deduced from the formula we gave in our paper for the calculation of the amount of silver deposited for a given exposure. This formula was, for the period of correct representation—

$$D = \gamma \log. \left(\frac{I t}{i} \right).$$

We should have to consider that in this formula the intensity of the light I is reduced by the negative, and we should have to divide I by the opacity of the negative, which in logarithmic calculation means deducting the logarithm of the opacity from the logarithm of the intensity of the light. But the logarithm of the opacity is the density as measured by our instrument, which density we simply subtract, and, in order to prevent confusion, we mark the densities of negatives, including the fog, by N , and the densities of positives by P . The equation which results, if we introduce at the same time the correction α of the negative density for the reasons just explained, stands thus:—

$$P = \gamma \left[\log. \frac{I t}{i} - \alpha N \right]$$

and this equation represents the general relation between a negative and its positive. P is the density of the positive produced behind the negative of density N upon a plate of inertia i by means of the light intensity I in the time t .

The coefficient α which converts the density, as measured, into the printing density is, for negatives, developed by ferrous oxalate, usually a fraction; for pyro-developed

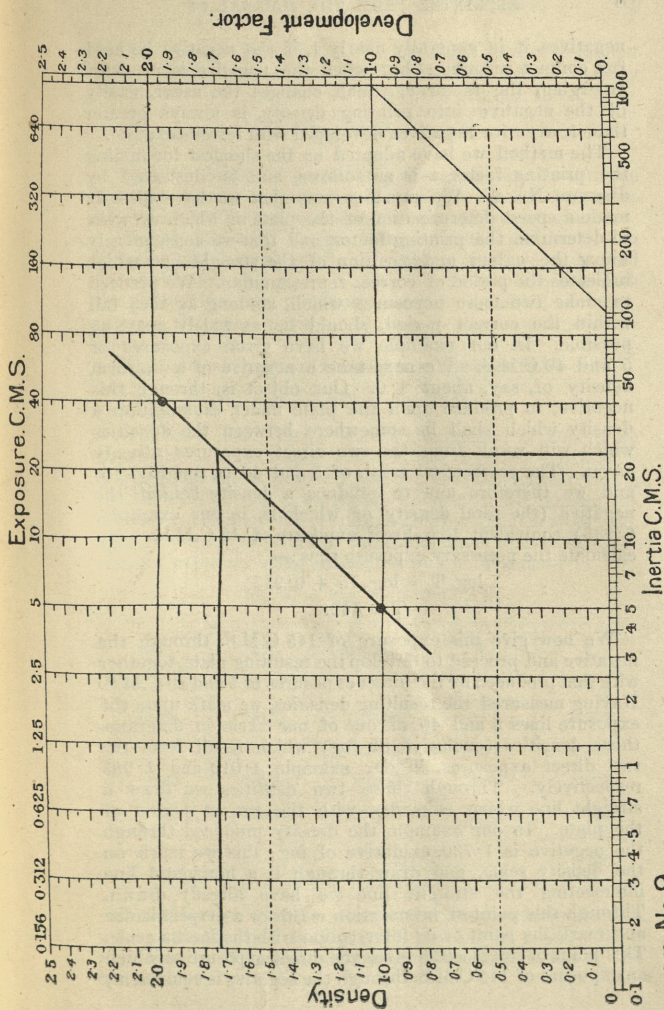


Diagram No. 9.

negatives it is generally nearly 1, if the negative be used for contact printing; but when the negative is used for enlarging, the factor α , which changes the usual density of the negative into printing density, is always greater than 1, even for negatives developed with ferrous oxalate.

The method we have adopted as the simplest for finding the printing factor α is as follows, and is illustrated by diagram No. 9. We must assume that we have already made a speed determination of the plate of which we wish to determine the printing factor, and that we consequently know the extent and position of the straight line which indicates the period of correct representation. We proceed to make two more exposures which, so long as they fall within the correct period, should lie as widely apart as possible. In our example we have given exposures of 5 and 40 C.M.S. We next take a negative of a uniform density of, say, about 1.0. Our object is, through this negative, to produce upon the plate under examination a density which shall lie somewhere between the densities which will result from the two direct exposures already given. The geometrical mean of 5 and 40 is, roughly, 15, and we therefore aim to produce a density behind the negative (the total density of which is, in our example, 0.985) equivalent to a direct exposure of 15 C.M.S. We calculate the necessary exposure thus:—

$$\log. T = \log. 15 + 0.985$$

$$T = 145.$$

We now give this exposure of 145 C.M.S. through the negative and proceed to develop the resulting plate, together with that produced by the direct exposures of 5 and 40 C.M.S. Having measured the resulting densities, we mark upon the exposure lines 5 and 40 of one of our skeleton diagrams those densities (exclusive of fog) which result from the two direct exposures, in our example 1.010 and 1.965 respectively. Through these two densities we draw a straight line which coincides with the correct period of the plate. In our example the density produced through the negative is 1.730, exclusive of fog; this we mark on the density scale, and draw through it a horizontal line intersecting the straight line we have already drawn. Through this point of intersection we draw a perpendicular and mark the point of its intersection with the inertia scale. This point of intersection gives the direct exposure to which an exposure of 145 C.M.S. through the negative is equivalent,

in this example 24 C.M.S. We have now merely to deduct log. 24 from log. 145 and divide the result by the density of the negative used, and we obtain the printing factor α :—

$$\frac{\log. 145 - \log. 24}{\cdot 985} = 0 \cdot 79$$

That this mode of converting the visual density into the printing density is correct practically, even for the errors caused by mutual reflection, is best proved by experiment.

Having measured in our instrument the densities of a negative with a number of different but uniform tints, and found the densities to be N_1, N_2, N_3 , &c., we can calculate the time of exposure necessary to produce, behind each tint, exactly the same positive density if once we know the factor α .

The times of exposure are given by the equation—

$$\log. t - \alpha N = \text{constant.}$$

We have made many such experiments, of which we quote one as an example. Behind the negative densities N it was proposed to produce positive densities corresponding to 15 C.M.S. direct exposure upon a plate known as "Barnet ordinary," the printing factor for which is $\alpha = 0 \cdot 665$. The following table shows the calculations and results, the time of exposure being calculated by the formula—

$$\log. T = \log. 15 + 0 \cdot 665 N.$$

N.	αN .	log. T.	T.	P.
1·230	·8179	1·9939	Seconds. 98·6	1·300
·965	·6417	1·8177	65·7	1·310
·660	·4389	1·6149	41·2	1·330
·390	·2593	1·4353	27·2	1·285
Mean.....				1·306

It will be seen that the densities of the resulting positive were as nearly equal as they could possibly be made. Such experiments, of course, require an exact knowledge of the factor α .

The mode of correcting the visual density for mutual reflection and colour can, however, be proved correct in another way, which does not involve a previous knowledge of the factor α .

The formula $P = \gamma \left(\log. \frac{I t}{i} - \alpha N \right)$ becomes by transposition $P + \alpha \gamma N = \gamma \log. \frac{I t}{i}$. Since when exposing a sensitive plate behind a negative, the intensity of the light I in front of the negative, the time of exposure, and the inertia of the sensitive plate are all the same, the sum $P + \alpha \gamma N$ must be the same for any corresponding points of the negative and positive. If, therefore, we print a positive from a negative, ensuring such exposures as fall within the period of correct representation, measure the resulting densities, and then form the sum $P + \alpha \gamma N$, this sum must be constant. Since $P + \alpha \gamma N = c$ is the equation of a straight line, we can show this property graphically without knowing $\alpha \gamma$. We simply choose the densities of the negative as abscissæ, the densities of the positive as ordinates, and join the points which should form a straight line if the proposition is correct. We give a few experiments of this description.

Experiments made in 1887. $P + 1.6 N = 3.083$.

Negative Density, N.	Positive Density, P.	$P + 1.6 N$.	Error.
0.700	1.960	3.080	- .003
0.900	1.680	3.120	+ .047
1.010	1.480	3.096	+ .013
1.223	1.113	3.096	+ .013
1.285	1.010	3.060	- .023
1.360	.850	3.020	- .063
1.550	.530	3.010	- .073
1.660	.417	3.073	- .010

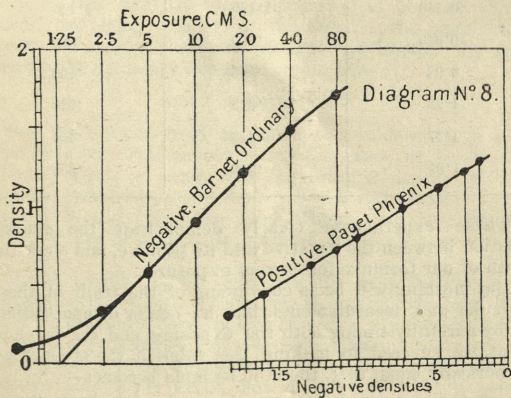
Experiment No. 2. $P + 1.5 N = 2.530$.

Negative Density, N.	Positive Density, P.	$P + 1.5 N$.	Error.
0.700	1.470	2.520	- .010
0.900	1.140	2.490	- .040
1.010	1.007	2.562	+ .032
1.223	.657	2.491	- .039
1.285	.547	2.474	- .056
1.360	.410	2.430	- .100
1.550	.270	2.595	+ .065
1.660	.190	2.680	+ .150

This experiment being made with a slow plate the last few positive densities fell into the period of under-exposure. It must not be forgotten that all the formulæ so far given only apply to the period of correct representation.

The following more recent and more complete experiment has been made the subject of a diagram to illustrate the graphic mode of proving that the actual exposures a plate receives behind a negative are accurately represented by our formulæ.

To diagram No. 8 the abscissæ are the densities of the negative, the ordinates the densities of the positive, and it



will be seen that all the points can be joined by a straight line, which proves that the printing densities of the negative were absolutely proportional to the densities as measured by our grease-spot photometer; were it otherwise the points would have been situated on a curve. The plate used for the positive was a Paget "Phoenix;" its constants had all been determined by special experiments, so as to make it possible to calculate beforehand the densities which ought to result. These constants were: Inertia = $6 \cdot 11$ C.M.S., printing factor $\alpha = 0 \cdot 577$, development factor, for $4\frac{1}{2}$ minutes at 60° F., $\gamma = 1 \cdot 03$. Behind a measured negative one of these plates was exposed for 134 seconds to a standard candle at 1 metre distance. The table shows the numerical results. The calculated densities are obtained by the formula—

$$P = 1 \cdot 03 \left[\log. \frac{.134}{6 \cdot 11} - 0 \cdot 577 N \right]$$

Negative Density (observed).	Positive Density (observed).	Positive Density (calculated).
0.165	1.270	1.285
0.255	1.225	1.230
0.440	1.120	1.120
0.670	.990	.982
0.98	.805	.800
1.28	.625	.620
1.57	.445	.450
1.81	.315	.300

These experiments clearly demonstrate the general relation between the negative and its positive, and show the truth of our formulæ for correct exposures.

But nothing will be so convincing of the truth of these formulæ and measurements than an ocular demonstration. If, by carefully timing both the exposure and the development, we succeed in making the value of the product $\alpha \gamma$ numerically equal to 1, then the formula becomes—

$$P + N = \text{constant},$$

Since P and N represent the visual densities of the negative and positive, this formula really tells us that, if such a positive is placed in juxtaposition with its negative, the picture should vanish totally; we ought to perceive nothing but a uniform tint all over the plate, since on every spot the sums of the positive and negative densities are alike. We show here a negative and positive, at present fastened together, which will prove this special case of our formulae, the only one which can be proved so readily. But it must not be supposed that every positive and every negative will do this; it is only when exposure and development have been carefully timed that this result is obtained.

We must now refer you again to diagram 8. If, on this diagram we produce the straight line until it intersects the scale of negative densities, the point of intersection would indicate the smallest negative density through which the standard candle, at one metre distance, would have been just unable to affect the plate in the 134 seconds given.

This leads us to the rule by which we ascertain the exposure necessary to produce with certainty a good positive transparency upon a given plate.

We first of all measure the highest density of the negative which we then correct with the factor α for the particular sensitive plate, and, knowing the inertia of the plate, we take care that the exposure shall be such that, behind the highest density of the negative, the plate shall receive an exposure at least equal to the inertia. By our formula the necessary exposure would be—

$$\log. T = \log. i + \alpha N.$$

But we do not need to make the calculation at all. Thanks to the arrangement of our diagrams, we need only take into a pair of compasses the printing density of the negative measured on the density scale, and measure from the inertia of the plate the same distance to the right on the exposure scale, and we read off at once the necessary exposure.

If the positive is to serve for the reproduction of a negative, it is absolutely necessary to continue development until the difference between two densities, say the extremes, is equal to the difference of the corresponding extremes in the negative. If the development is too short the resulting positive may look better, but it will not yield a good secondary negative.

By variations in the time of development it is possible to produce secondary negatives in which the scale of tones is either contracted or extended, and this function of development is of the utmost value in the production of special negatives for special printing processes.

It is undoubtedly a difficulty that, with one and the same negative, we have to multiply its densities as measured photometrically with different factors according to the plates we use with it. For negatives developed with ferrous oxalate the factor varies from about 0.6 to 1.0. We find it, however, sufficient for practical purposes to use the factor 0.8, but, of course, it is always better to ascertain the correct factor by experiment.

All this appears to be very complicated, but in actual practice it is very simple, as we shall now proceed to show. At the last meeting we produced, from a positive, a secondary negative, and we ascertained the necessary exposure as follows:—The highest density of the positive, as measured in our instrument, was 2.70, the printing factor α for the plate we used (Barnet) was 0.665, so that the highest printing density was $0.665 \times 2.70 = 1.7955$. We measured the amount, 1.795, or practically 1.800, with the compasses on the density scale, and carried this distance off on the exposure scale from the point 1.3 (the inertia of the Barnet plate). This indicated an exposure of 81 seconds, and this exposure we gave, the result proving it to have been correct.

To-night we propose to conclude our paper by producing two positive transparencies by contact printing on two plates of considerably different sensitiveness. The plates we shall use are Wratten "Ordinary" and "Instantaneous." The highest density of the negative we shall use is 2.385, and if you will refer to diagram No. 6, you will see how, from this density, we arrive at the exposure necessary for the two transparencies. We first of all multiply the density 2.385 by 0.8, and this gives the effective printing density 1.90 for the Wratten plates. We measure with compasses 1.9 on the density scale, and applying the compasses to the inertia of each plate, we read off, on the inertia scale, exposures of 87 and 1,200 C.M.S. for the "instantaneous" and "ordinary" plates respectively.

We will expose the "instantaneous" plate first, but instead of giving an exposure of 87 seconds at a distance of 1 metre from the candle, we will, to save time, give

43 $\frac{1}{2}$ seconds at a distance of 0.707 of a metre. Having made this exposure, we will proceed to expose the "ordinary" plate. The exposure indicated is 1,200 C.M.S., which amounts to 20 minutes, and, as we do not wish to tax your patience to this extent, we will show you how we curtail a too lengthy exposure. Instead of using a candle, we will take a paraffin lamp, and we will find the distance at which it must be placed from the plate to be equal to 100 candles at 1 metre distance. To do this we hold a piece of white cardboard in the place of the sensitive plate, and, by means of a simple shadow photometer, we adjust the position of the lamp until its light is equal in intensity to that of 100 candles at a distance of 1 metre. We view the shadows through a piece of green glass in order to obviate the colour difficulty. We have now increased our light one hundred-fold, and the exposure we must give is consequently 12 seconds.



